SUPPLEMENTARY MATERIALS TO

Unoccupied aircraft systems (UAS) reveal the morphological changes at Stromboli volcano (Italy) before, between, and after the 3 July and 28 August 2019 paroxysmal eruptions

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Survey date	12/09/2018*	11/05/2019	20/06/2019	04-05/08/2019	23/09/2019	26/11/2019 (lava field only)	25/01/2020	20/06/2020
Photo alignment accuracy	High	High	High	High	High	High	High	High
Generic preselection	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reference preselection	Yes	Source	Source	Yes	Source	Source	Source	Yes
Key point limit	0	40000	30000	40000	40000	40000	40000	40000
Tie point limit	0	4000	1000	4000	4000	4000	4000	4000
Dense point cloud quality	High	High	High	High	High	High	High	High
Depth filtering	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive

*Table S1 - processing parameters used in Agisoft Metashape®. *Point cloud from Carr, 2019b.*

Reference model	Aligned model	Alignment rms Error (m)
2012 LiDAR	September 2018	0.39
September 2018	May 2019	0.26
September 2018	June 2019	0.32
September 2018	August 2019	0.77
September 2018	September 2019	0.63
September 2018	November 2019	0.17
September 2018	January 2020	0.40
September 2018	June 2020	0.57

Table S2 - Model alignments and associated rms errors reported in Cloud Compare software

Attribute	Raw	Thresholded DoD Estimate:			
AREAL:					
Total Area of Surface Lowering (m^2)	18,488	17,842			
Total Area of Surface Raising (m^2)	28,312	27,605			
Total Area of Detectable Change (m^2)	NA	45,447			
Total Area of Interest (m^2)	46,800	NA			
Percent of Area of Interest with Detectable Change	NA	97%			
VOLUMETRIC:				± Error Volume	% Error
Total Volume of Surface Lowering (m^3)	143,127	142,967	±	8,921	6%
Total Volume of Surface Raising (m^3)	212,744	212,566	±	13,803	6%
Total Volume of Difference (m^3)	355,871	355,533	±	22,724	6%
Total **Net** Volume Difference (m^3)	69,617	**69,600**	**±**	**16,435**	24%
VERTICAL AVERAGES:				± Error Thickness	% Error
Average Depth of Surface Lowering (m)	7.74	8.01	±	0.50	6%
Average Depth of Surface Raising (m)	7.51	7.70	±	0.50	6%
Average Total Thickness of Difference (m) for Area of Interest	7.60	7.60	±	0.49	6%
Average **Net** Thickness Difference (m) for Area of Interest	1.49	**1.49**	**±**	**0.35**	24%
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	7.82	±	0.50	6%
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**1.53**	**±**	**0.36**	24%
PERCENTAGES (BY VOLUME)					
Percent Elevation Lowering	40%	40%			
Percent Surface Raising	60%	60%			
Percent Imbalance (departure from equilibrium)	10%	10%			
Net to Total Volume Ratio	20%	20%			

Table S3 - Change detection results for the period May 2019 - September 2019 calculated over the Crater Terrace Area Of Interest (CT-AOI)

Attribute	Raw	Thresholded DoD Estimate:			
AREAL:					
Total Area of Surface Lowering (m^2)	4.760	4.167			
Total Area of Surface Raising (m^2)	42.040	41.307			
Total Area of Detectable Change (m^2)	NA	45.474			
Total Area of Interest (m^2)	46.800	NA			
Percent of Area of Interest with Detectable Change	NA	97%			
VOLUMETRIC:				± Error Volume	% Error
Total Volume of Surface Lowering (m^3)	19.219	19.077	±	2.084	11%
Total Volume of Surface Raising (m^3)	466.601	466.412	±	20.654	4%
Total Volume of Difference (m^3)	485.820	485.490	±	22.737	5%
Total **Net** Volume Difference (m^3)	447.383	**447.335**	**±**	**20.758**	5%
VERTICAL AVERAGES:				± Error Thickness	% Error
Average Depth of Surface Lowering (m)	4,04	4,58	±	0,50	11%
Average Depth of Surface Raising (m)	11,10	11,29	±	0,50	4%
Average Total Thickness of Difference (m) for Area of Interest	10,38	10,37	±	0,49	5%
Average **Net** Thickness Difference (m) for Area of Interest	9,56	**9,56**	**±**	**0,44**	5%
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	10,68	±	0,50	5%
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**9,84**	**±**	**0,46**	5%
PERCENTAGES (BY VOLUME)					
Percent Elevation Lowering	4%	4%			
Percent Surface Raising	96%	96%			
Percent Imbalance (departure from equilibrium)	46%	46%			
Net to Total Volume Ratio	92%	92%			

Table S4 - Change detection results for the period September 2018 - June 2020 calculated over the Crater Terrace Area Of Interest (CT-AOI)

Check Point Id	12/09/2018	11/05/2019	04-05/08/2019	23/09/2019	25/01/2020	20/06/2020
0	829.24				829.61	829.73
1	767.41	767.34	767.60	767.84	767.68	767.75
2	796.84	796.83	797.80	797.60	796.91	796.84
3			737.44		737.88	737.87
4					794.18	793.93
5	684.58		684.39	684.41	684.50	684.25

Table S5 - Elevation values (in m) extracted at 5 checkpoints placed in the unchanged regions of our DSMs.

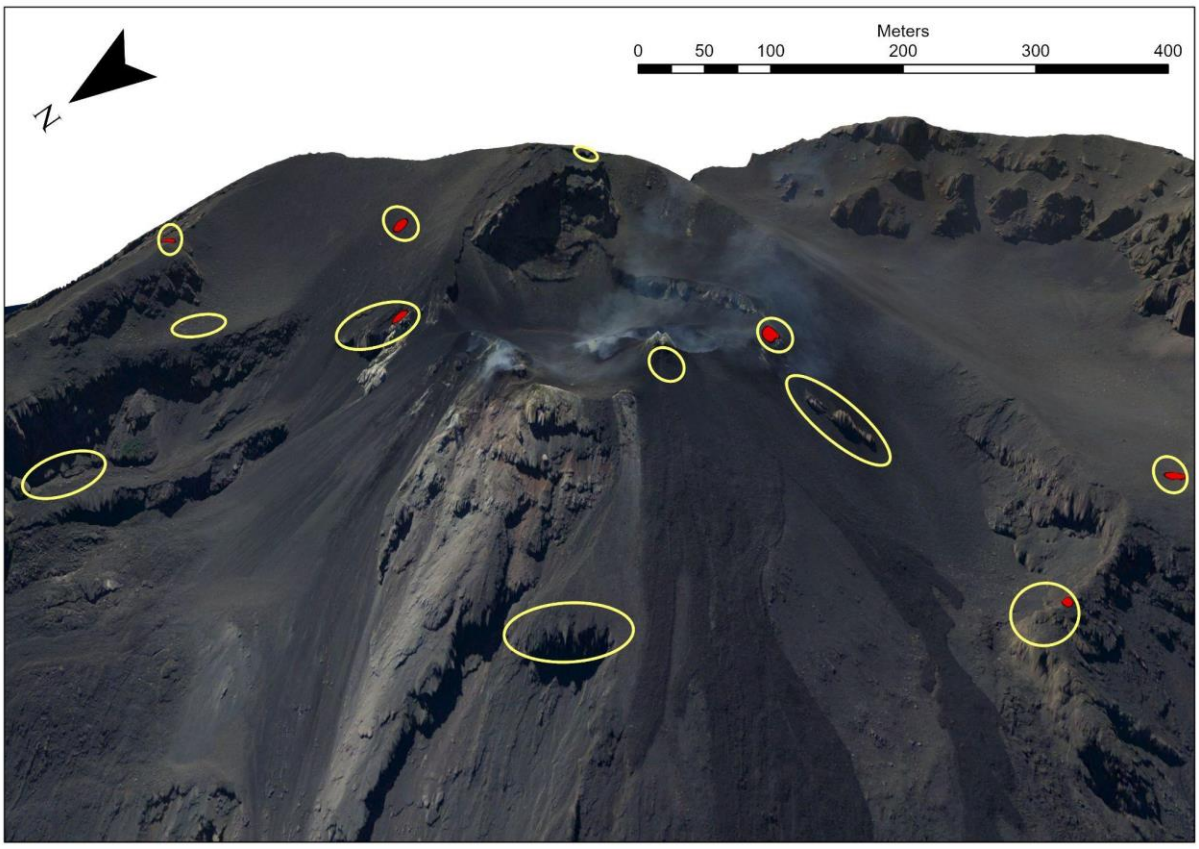

Figure S1. Features located in unchanged areas of the volcano used for the alignment of the models (yellow ellipses). Red dots indicate the checkpoints used to compute residual elevation differences (see section 2.2).

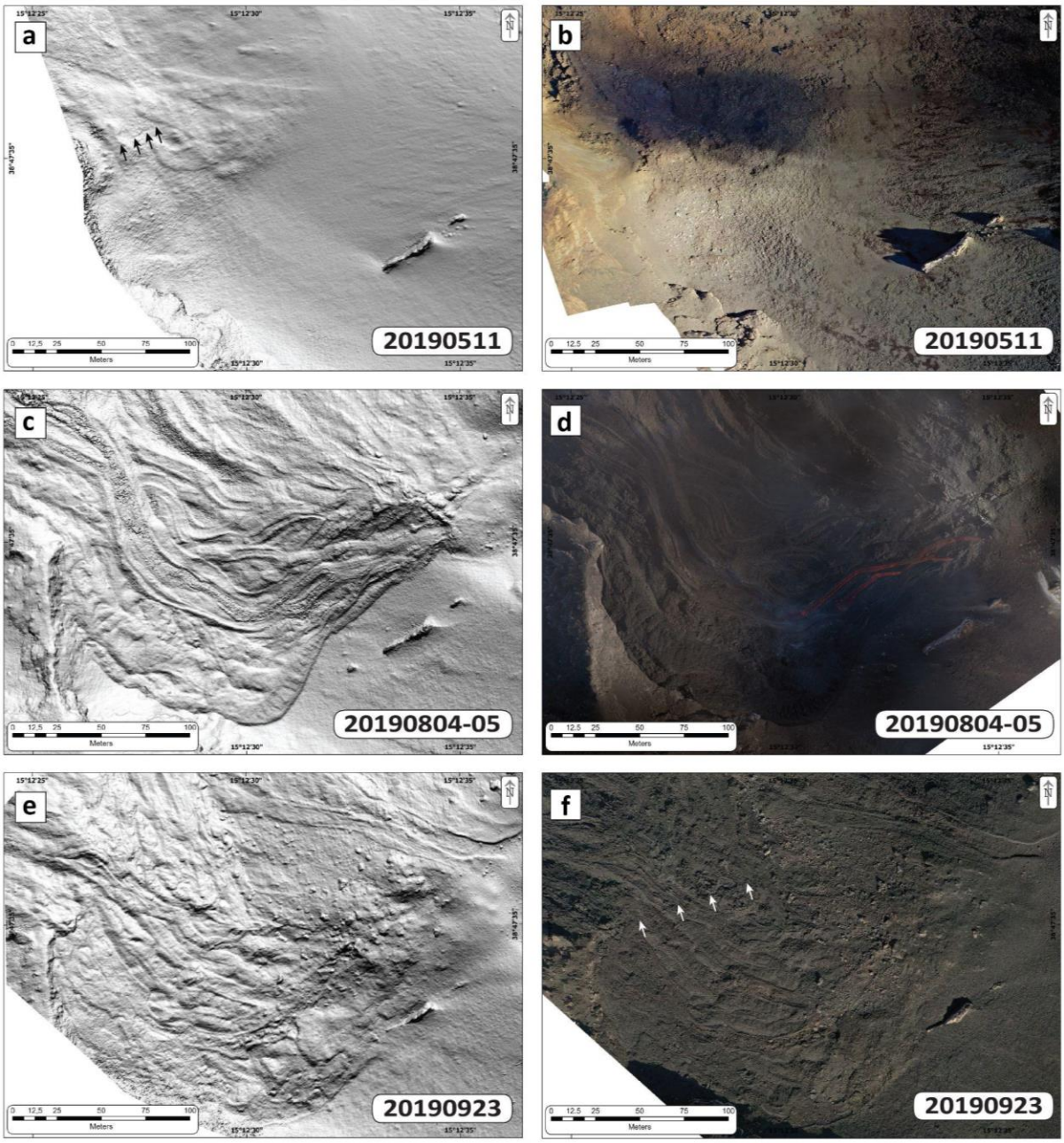

Figure S2 - DSMs and orthomosaics of the lava field area. Arrows in a) and f) indicate the surface expression of the main N30° fissure belonging to the "fratture Tibaldi" fissure swarm (see Figure 8 in the main text).

Figure S3 - Alignment of hornitos in the N crater area (in the foreground) and plume rising from two vents located in the CS crater area (in the upper right background). Photo taken 05 August 2019.

Figure S4 - Block deposited on the SdF on 28 August 2019 (in the foreground) and the crater terrace rim (in the upper right background).

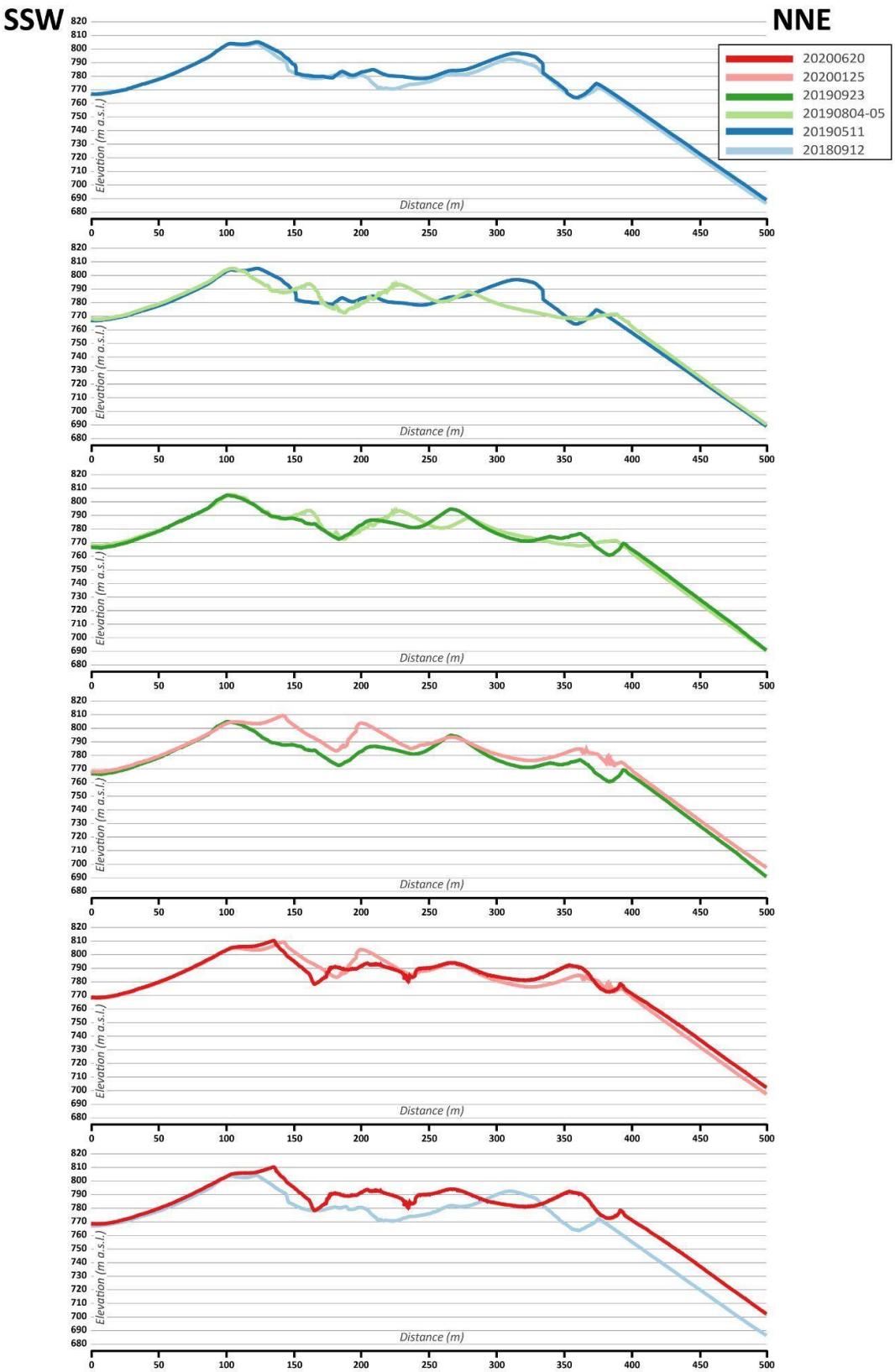

Figure S5 - Cross-sections of the crater terrace through time (12 September 2018 to 20 June 2020) along profile 1 in Figure 5.

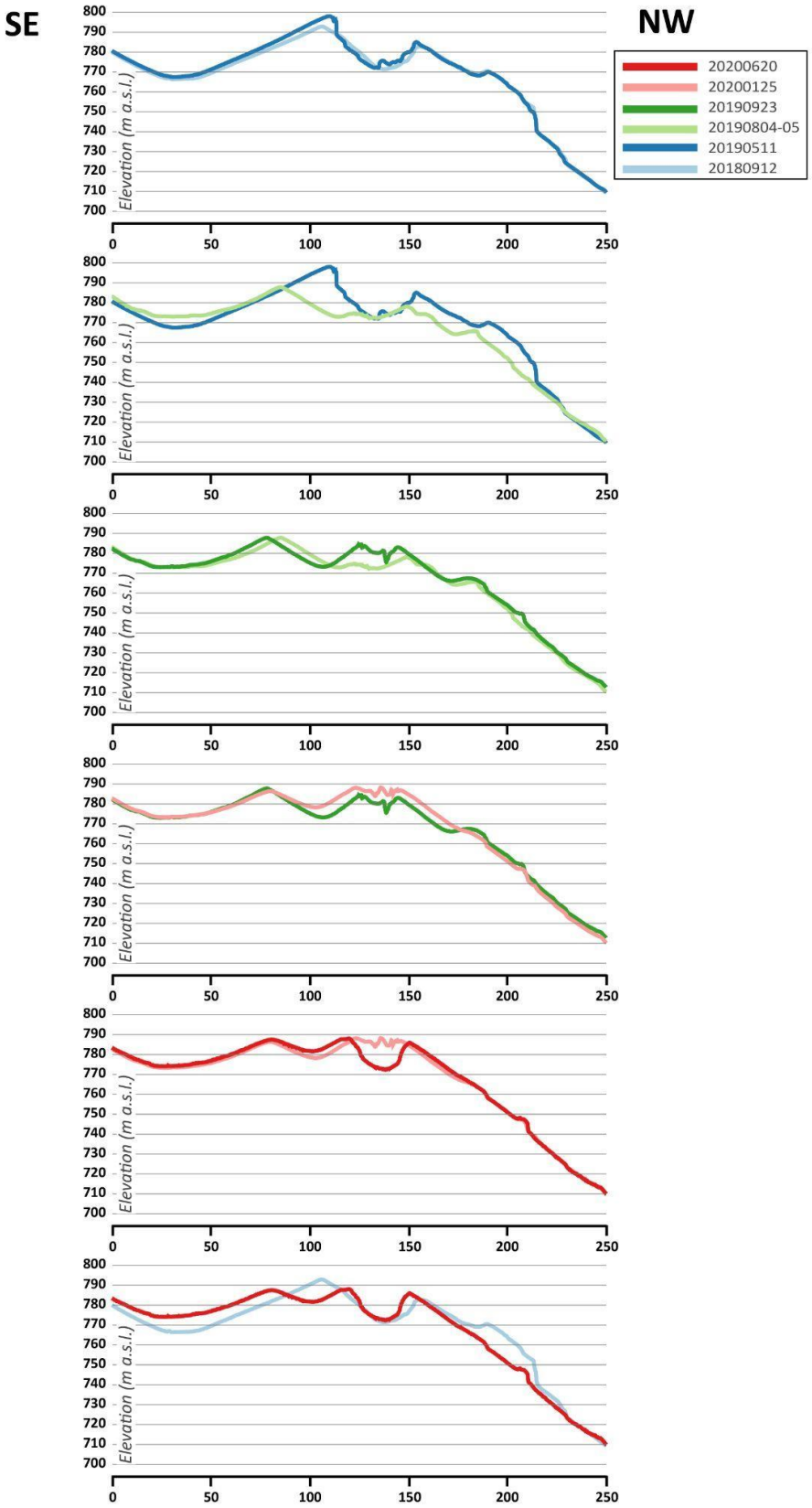

Figure S6 - Cross-sections of the SW crater area and upper SdF through time (12 September 2018 to 20 June 2020) along profile 2 in Figure 5.

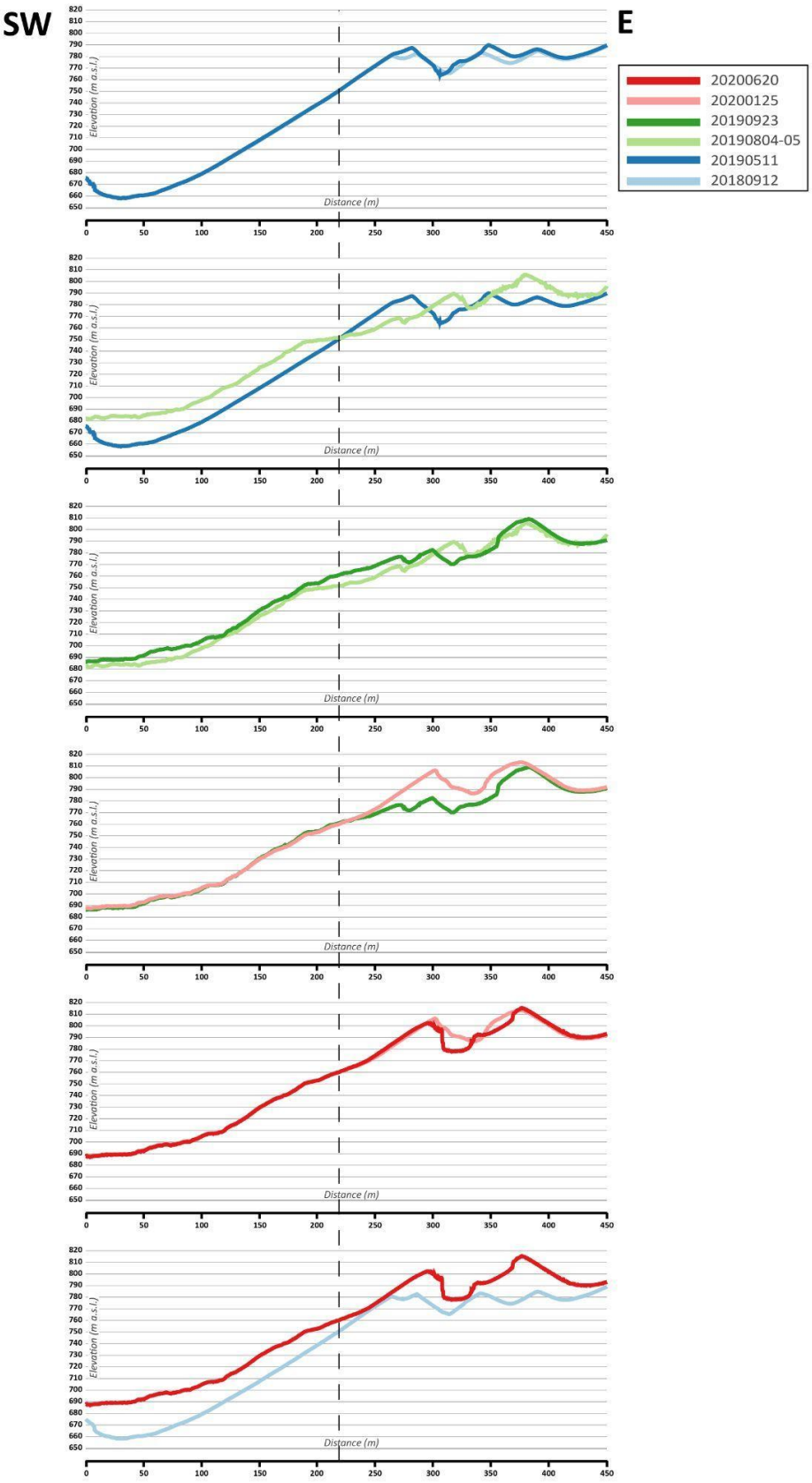

Figure S7 - Cross-sections of the lava field and CS crater area through time (12 September 2018 to 20 June 2020) along profile 3 in Figure 5.

Figure S8 - Lava field and active lava flows in the upper SdF on 4 August 2019.

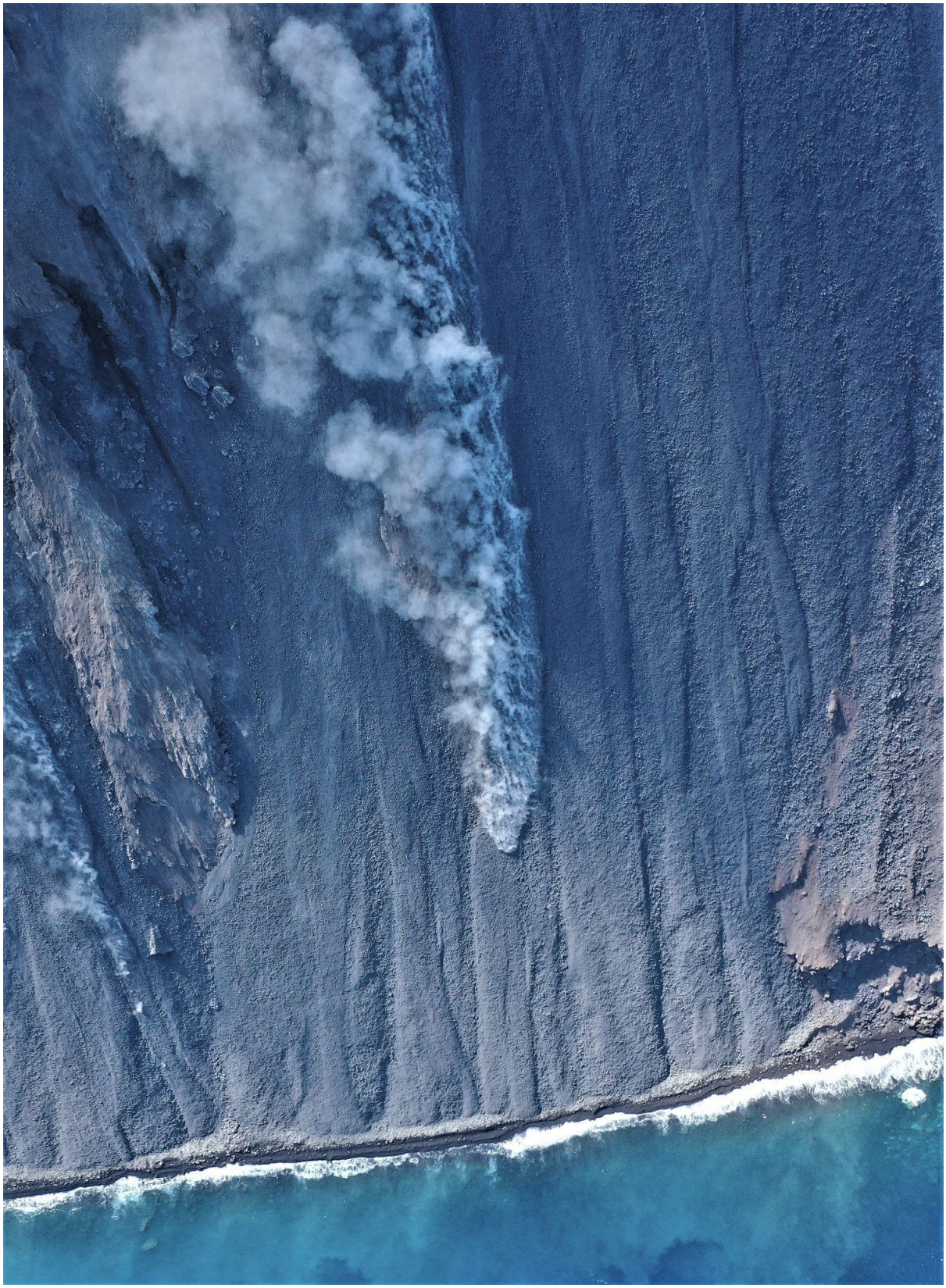

Figure S9 - Characteristic morphology of gravel flow deposits at the foot of the SdF slope and an active gravel flow descending it (5 August 2019).

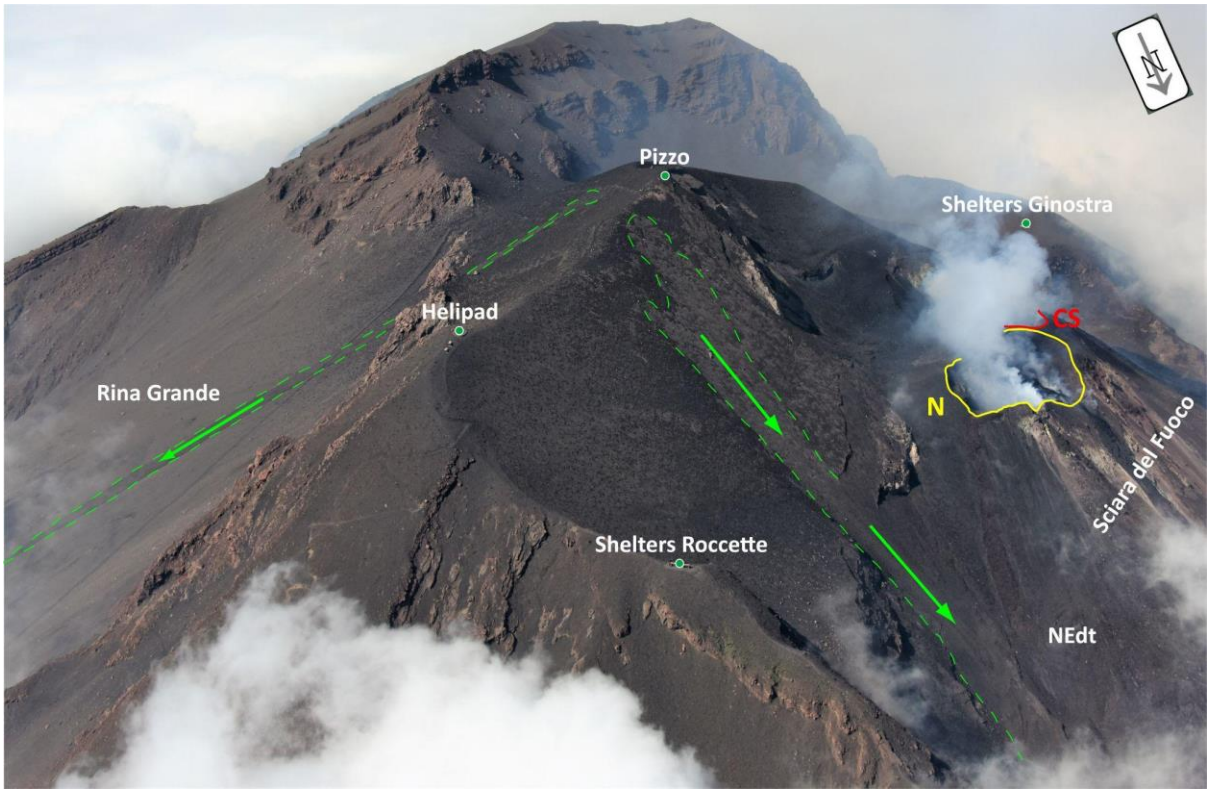

Figure S10 - Gravel flows descending from the Pizzo area within Rina Grande (green arrow on the left) and towards the NEdt sector (green arrows on the right). Photo by S. Branca, INGV-OE, 4 July 2019.

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